

DEVELOPMENT OF AN AC-DC BOOST POWER FACTOR CORRECTION

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*Special dedication to my beloved family,
Md Tahir Bin Abd Rahman, Sulbiah Bte Samah (Parent),
Suhaida Binti Muhamamd (Wife)
Arieq Zafri Bin Zuraidi (Son),
Aqief Zikri Bin Zuraidi (Son),
All family members*



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ABSTRACT

With rapid development in power semiconductor devices, the usage of power electronic systems has expanded to new and wide application range that include residential, commercial, aerospace and many others. Power electronic interfaces such as switch mode power supplies have proved to be superior over traditional linear power supplies. However, their non-linear behavior puts a question mark on their high efficiency. The current drawn by the switch mode power supplies from the line is distorted resulting in a high Total Harmonic Distortion and low Power Factor. Power Factor, the ratio between the real or average power and the apparent power forms a very essential parameter in power system. It is indicative of how effectively the real power of the system has been utilized. With the stringent requirements of power quality, power factor correction has been an active research topic in power electronics, and significant efforts have been made on the developments of the power factor correction converters. This project aims to develop a circuit for power factor correction using active filtering approach by implementing boost converters arranged in parallel. It shall be based on an optimized power sharing strategy to improve the current quality and at the same time reduce the switching losses. The simulation result shows that the power factor was improved when the power factor corrector circuit added to the inverter and the power factor corrector circuit switching with proportional-integral-derivative controller shows better power factor then using pulse width modulation switching mode.

ABSTRAK

Peningkatan dalam penggunaan peralatan yang menggunakan peranti kuasa separapengalir menyebabkan sistem elektronik kuasa telah berkembang luas dalam penggunaannya termasuk dalam kediaman, perdagangan, industri angkasa lepas dan banyak lagi. Sistem elektronik kuasa seperti *switch mode power supplies* merupakan salah satu penukar sistem kuasa arus ulangalik kepada arus terus yang biasa digunakan. Walaubagaimanapun, penggunaannya boleh dipersoalkan kerana tidak konsisten dalam mengekalkan kecekapan yang tinggi. Arus yang dikeluarkan dengan penggunaan sistem *switch mode power supplies* akan terganggu dan akan menyebabkan berlakunya harmonik dan akan menyebabkan faktor kuasa menurun. Faktor kuasa merupakan nisbah diantara kuasa sebenar dan kuasa ketara. Faktor kuasa adalah alat pengukur yang menunjukkan betapa efektifnya penggunaan kuasa sebenar dalam sesuatu sistem. Dengan peningkatan keperluan untuk mengekalkan faktor kuasa yang baik, kajian terhadap sistem penambahbaikan kepada faktor kuasa juga meningkat di dalam bidang elektronik kuasa dan banyak usaha telah dijalankan untuk mendapatkan atau pembangunan penukar arus ulang alik kepada arus terus dengan pembetulan faktor kuasa. Projek ini bertujuan untuk membangunkan litar penukar dari arus ulang alik kepada arus terus yang mempunyai kebolehan untuk memperbaiki faktor kuasa dengan menggunakan penapis aktif iaitu penambahan boost converter yang dipasang selari dengan penukar dari arus ulang alik kepada arus terus. Penambahan ini akan dapat meningkatkan kualiti factor kuasa dan seterusnya dapat mengurangkan kehilangan yang disebabkan oleh pensuisan. Dari sumilasi yang dijalankan, didapati faktor kuasa telah dapat dipertingkatkan apabila litar penambahbaikan faktor kuasa telah ditambah kepada litar asal dan litar penambahbaikan faktor kuasa yang menggunakan proportional-integral-derivative controller sebagai pengawal pensuisan dapat memperbaiki factor kuasa dengan lebih baik berbanding litar penambahbaikan faktor kuasa yang dikawal menggunakan pulse width modulation.

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PTTHM
PERPUSTAKAAN TUNKU TUN AMINAH

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Power factor is defined as the cosine of the angle between voltage and current in an ac circuit. There is generally a phase difference ϕ between voltage and current in an ac circuit. $\cos \phi$ is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading.

In a circuit, for an input voltage V and a line current I ,

$VI \cos \phi$ – the active or real power in watts or kW.

$VI \sin \phi$ - the reactive power in VAR or kVAR.

VI - the apparent power in VA or kVA.

Power Factor gives a measure of how effective the real power utilization of the system is. It is a measure of distortion of the line voltage and the line current and the phase shift between them.

$$\text{Power factor} = \frac{\text{Real Power (Average)}}{\text{Apparent power}}$$

Where, the apparent power is defined as the product of rms value of voltage and current.

In a purely resistive AC circuit, voltage and current waveforms are in step (or in phase), changing polarity at the same instant in each cycle. Where reactive loads are present, such as with capacitors or inductors, energy storage in the loads result in a time difference between the current and voltage waveforms. This stored energy returns to the source and is not available to do work at the load. A circuit with a low power factor will have thus higher currents to transfer at a given quantity of power than a circuit with a high power factor.

In recent years, there have been increasing demands for high power factor and total harmonic distortion in the current drawn from the utility. With the stringent requirements of power quality [1], power factor corrector has been an active research topic in power electronics, and significant efforts have been made on the developments of the power factor corrector converters [2]. In general, the continuous-conduction mode (CCM) boost topology has been widely used as a power factor corrector converter because of its simplicity and high power capability. It can be used with the universal input voltage range.

The work initially involves simulation of basic power electronic circuits and the analysis of the current and voltage waveforms. All the simulation work is done in MATLAB Simulink environment and the results are attached herewith. After the performance of the proposed converter is acceptable, the proposed rectifier prototype is built to verify the operation; the critical relationships of voltage boost and simulation results are presented.

1.2 Problem Statements

Dc power supplies are extensively used inside most of electrical and electronic appliances such as in computers, monitors, televisions, audio sets and others. The high power non linear loads such as static power converter, arc furnace and adjustable speed drives or low power loads such as fax machine and computer can produce voltage fluctuations, harmonic currents and an imbalance in network system which results into low power factor operation of the power system [3]. There is a need of

improved power factor and reduced harmonics content in input line currents as well as voltage regulation during power line over-voltage and under voltage conditions.

1.3 Project Objectives

This project has been developed to enhance the achievement in the following matter:-

- a) Develop modelling of Ac to Dc converter.
- b) Develop simulation modeling of open loop PFC of Boost Converter using software MATLAB simulink.
- c) Develop simulation modeling of closed loop PFC of Boost Converter using software MATLAB simulink.

1.4 Project scopes

The scope of this project is to develop simulation modelling for boost converter and all of the projects modeling are carried out in simulation method only using MATLAB Simulink software.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Conventionally, ac-dc converters, which also called rectifier, are developed using diodes and thyristors to provide controlled and uncontrolled dc power with power flow. These converters can be subclassified into 4 types as boost, buck, buck-boost and multilevel with unidirectional and bidirectional power flow [4]. There are three basic types of ac to dc converter circuits with PFC is discuss in this chapter, termed as buck, boost and buck boost with unidirectional power flow and also discuss about power factor.

2.2 Related work

Power factor correction has become an increasing demand feature in ac-dc power supplies in recent years. Standards such as EN61000-3-2 have imposed restriction on line current harmonic pollution. It has become standard practice to implement an ac-dc converter by placing a boost converter. Therefore, different variations on this converter have been proposed and many of these have been attempted to reduce conduction losses and component numbers as shown in international conference proceedings and journal publications in the past few years.

M. Gopinath and D. Yogeetha (2009) performed a comparative evaluation of the Bridgeless topology followed by the full-bridge with 1 DC/DC converter. Several issues will be highlighted and most of them are concerned on the efficiency of the converter at low power operation which is 300W or less. For Full-bridge with 1 DC/DC converter, only one DC/DC converter is used, and that's the reason why this topology is classified as single-stage PFC. Figure 2.1: shows the general circuit diagram for single-stage PFC circuit.

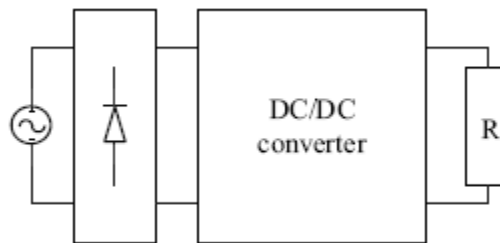


Figure 2.1: Converter arrangement for full-bridge rectifier with 1DC/DC converter

For Bridgeless converter as shown in Figure 2.2 (a): topology does not have rectifier circuit operated throughout the full cycle and that's the reason for its name. Figure 2.2(b) shows one of the earliest topology in this class which is called the Bridgeless Boost PFC

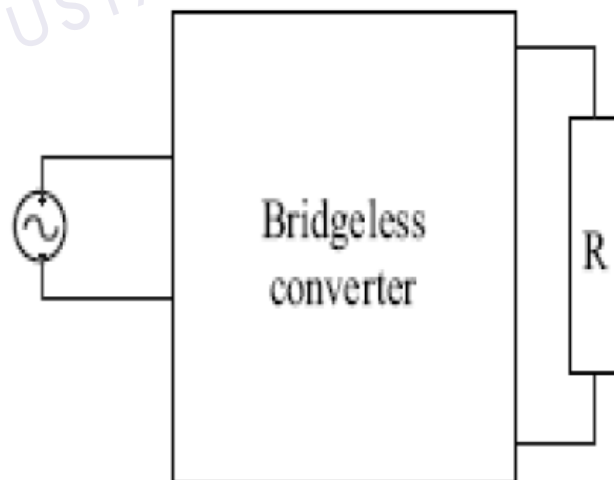


Figure 2.2 (a): Converter arrangement for Bridgeless converter.

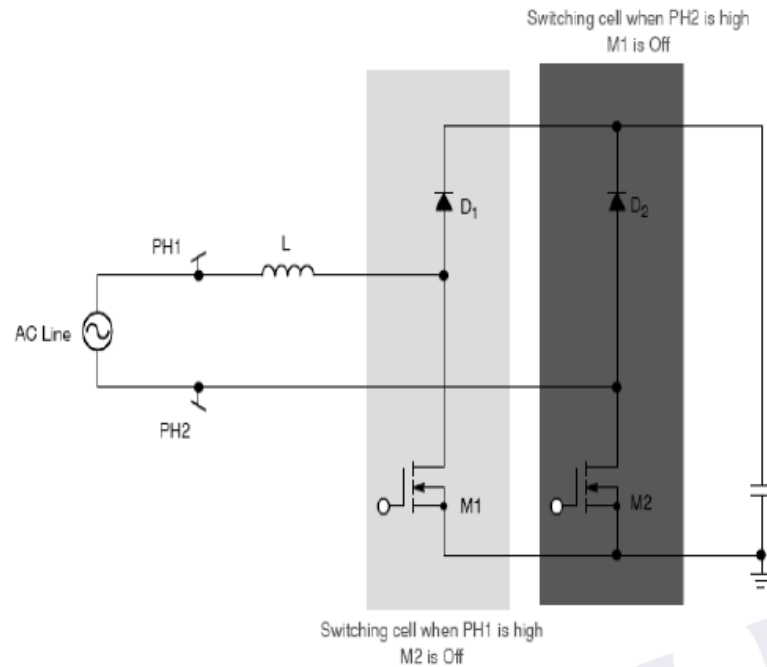


Figure 2.2 (b): Bridgeless Boost PFC.

Based on the Two PFC topologies, it is found that the best efficiency is obtained from the Bridgeless topology followed by the full-bridge with 1 DC/DC converter. It is found that by using less number of components, the efficiency can be improved up to 8% and in some cases up to 10% as explained previously. However, the Bridgeless converters discussed in this paper were unable to be used as switch mode power supplies due to its output voltage which is not regulated at 19V. On top of that, it can be observed that several works have been using variable switching frequency especially for fully DCM or CCM/DCM boundary operation [6].

A. Jangwanitlert and J. Songboonkaew applied and testing a soft-switch ac-dc symmetrical boost converter with power factor correction. The rectifier is modified boost voltage that is well suited for low line input applications and operated with half of the switch voltage stress than those found in standard boost converter. Soft-switching in the boost converter is achieved under Zero-Voltage Switching (ZVS) turn on and Zero-Current Switching (ZCS) at turn on, quasi resonant technique [7].

Figueiredo, J.P.M., Tofoli, F.L., and Silva, B.L.A. present and summarize the characteristics of several single phase boost-based topologies dedicated to PFC. The study is based on the careful analysis of several works available in the literature and intends to be consolidated as a fast and concise guide for researchers that are

eventually interested in using boost topologies for PFC applications. The exposition of six types of arrangement is expected to present the evolution of the boost converter and also provide easy selection of an appropriate topology for a given application. While dedicated to highlight some of the main characteristics regarding the converters, the paper seeks to motivate the reader to analyze some of the most important publications related to the theme by adequately citing them.

2.3 Theories

2.3.1 AC to DC Converter

Ac to Dc converter or bridge rectifier convert an alternating current (AC) input into direct current a (DC) output, refer Figure 2.3. Figure 2.4 below show the current path during operating. When ac voltage is applied to the four-diode full-wave bridge rectifier, the positive half of the sine wave will be rectified by diodes 1 and 3. The negative half of the sine wave is rectified by diodes 2 and 4. From the top circuit in Fig. 2.4 notice that the positive half-cycle of the ac is shaded, and the first half-wave is shaded to indicate the output for this part of the circuit. The bottom circuit shows the negative half of the sine wave being rectified. The path the electrons would travel through the bridge is also shown. Notice that electron flow is always against the arrows of the diodes.

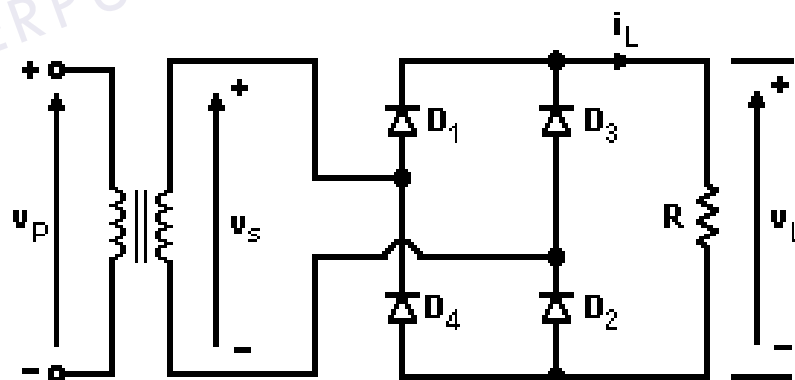


Figure 2.3 (a): Circuit diagram for Ac to Dc converter or bridge rectifier convert an alternating current (AC)

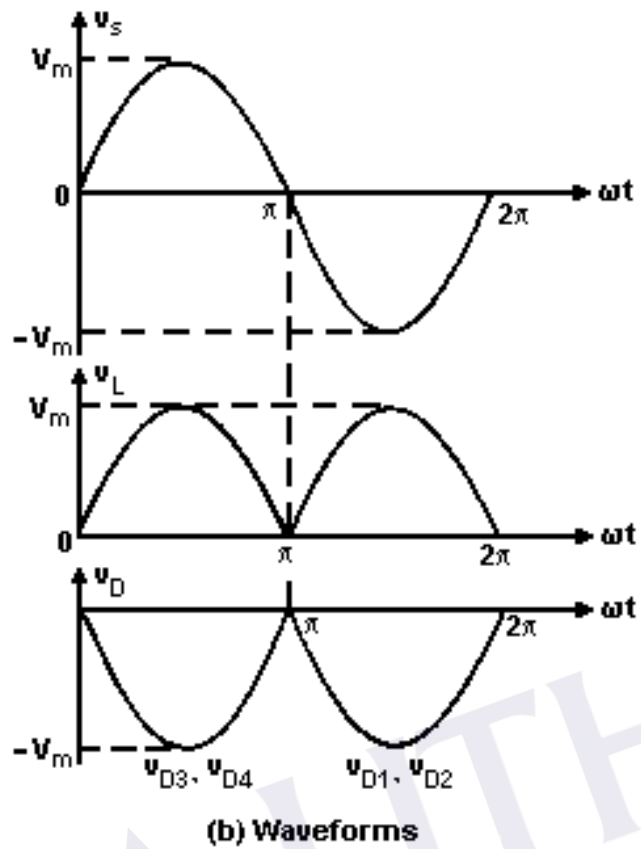


Figure 2.3(b): Ac to Dc converter or bridge rectifier convert an alternating current (AC) waveform

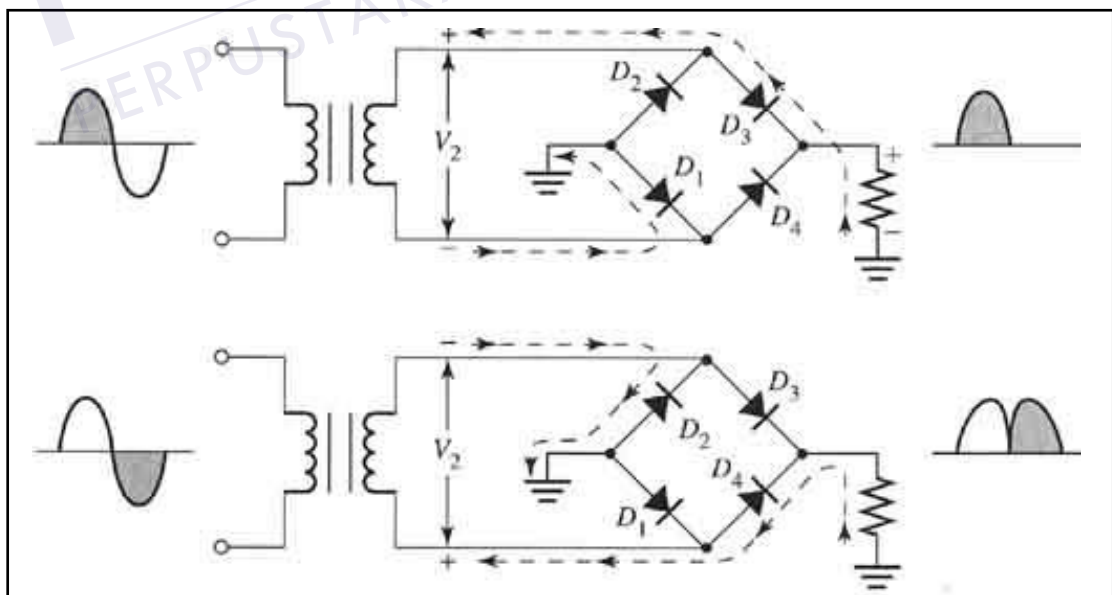


Figure 2.4: current path during operating.

2.3.2 Buck

A buck converter is shown in Figure 2.5 below. In principle, it is a combination of diode rectifier with step down chopper with input and output filter. Its performance is improved using a ripple filter at dc output for reducing harmonics in ac mains and ripples at dc output voltage. Nowadays, it is also developed using a diode rectifier with filter and various combinations of dc–dc converter with and without high-frequency transformer isolation [4].

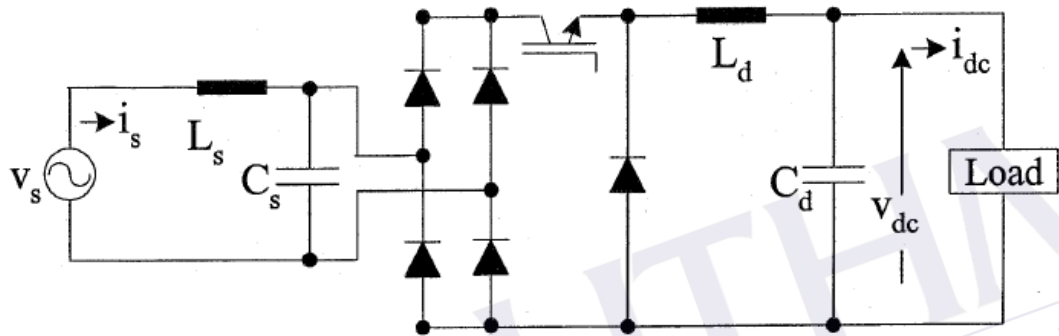


Figure 2.5: Rectifier circuit with Buck Converter

2.3.3 Buck Boost

A buck boost converter is shown in Figure 2.6 below. In principle, it is a combination of diode rectifier with buck–boost dc–dc converters [4].

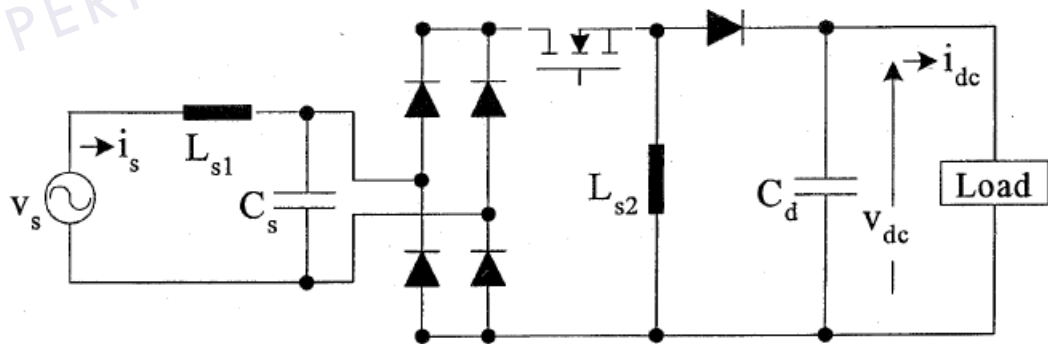


Figure 2.6: Rectifier circuit with Buck-Boost Converter

2.3.4 Boost

A boost converter is shown in Figure 2.7 below. In principle, it is a combination of diode bridge rectifier and step up dc chopper with filtering and energy storage elements. These converters are extensively used in electronic ballast, power supplies, variable-speed ac motor drives in compressor, refrigerator, pumps, fans, etc [4].

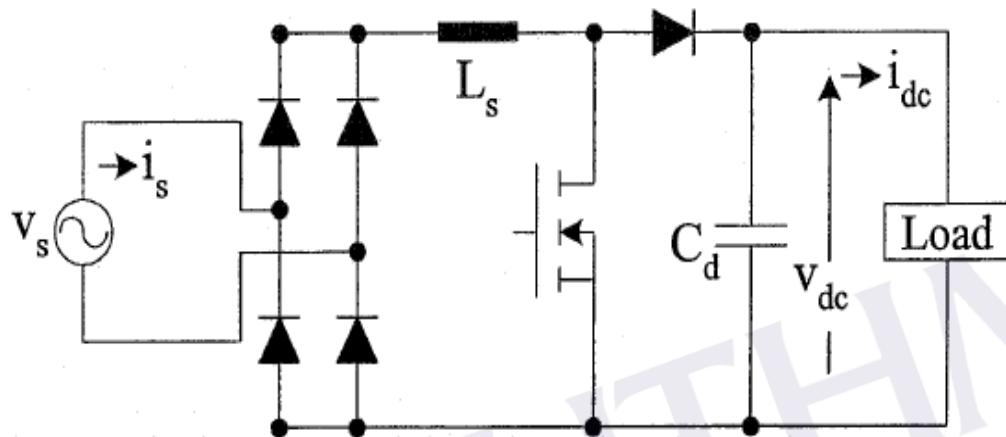


Figure 2.7: Rectifier circuit with Boost Converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores the energy. Polarity of the left side of the inductor is positive. When the switch is opened, current will be reduced as the impedance is higher. Therefore, change or reduction in current will be opposed by the inductor. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch.

The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

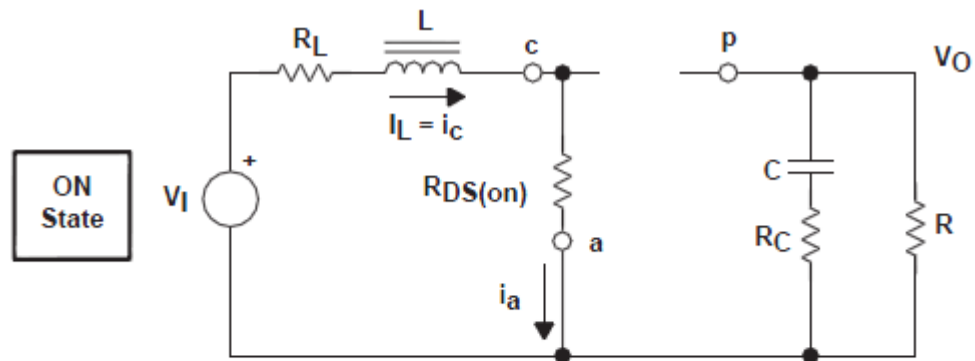


Figure 2.8 (a): Configurations of a boost converter, on state of the switch S.

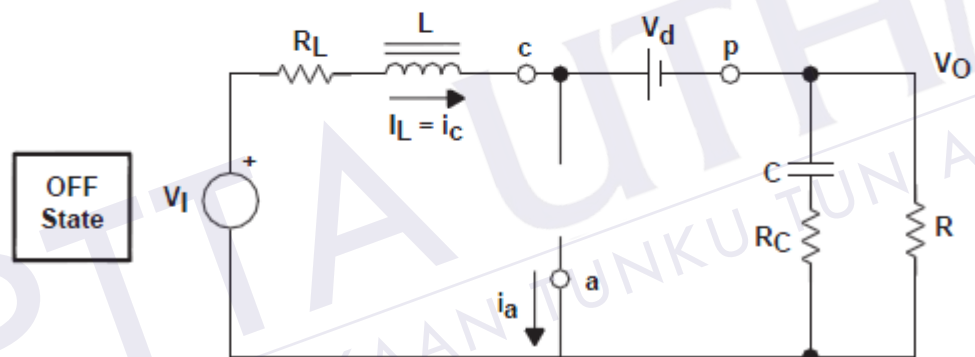


Figure 2.8 (b): Configurations of a boost converter, off state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states as shown in figure 2.8. In the On-state, the switch S is closed, resulting in an increase in the inductor current, in the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor. The input current is the same as the inductor current as can be seen in figure 2.9.

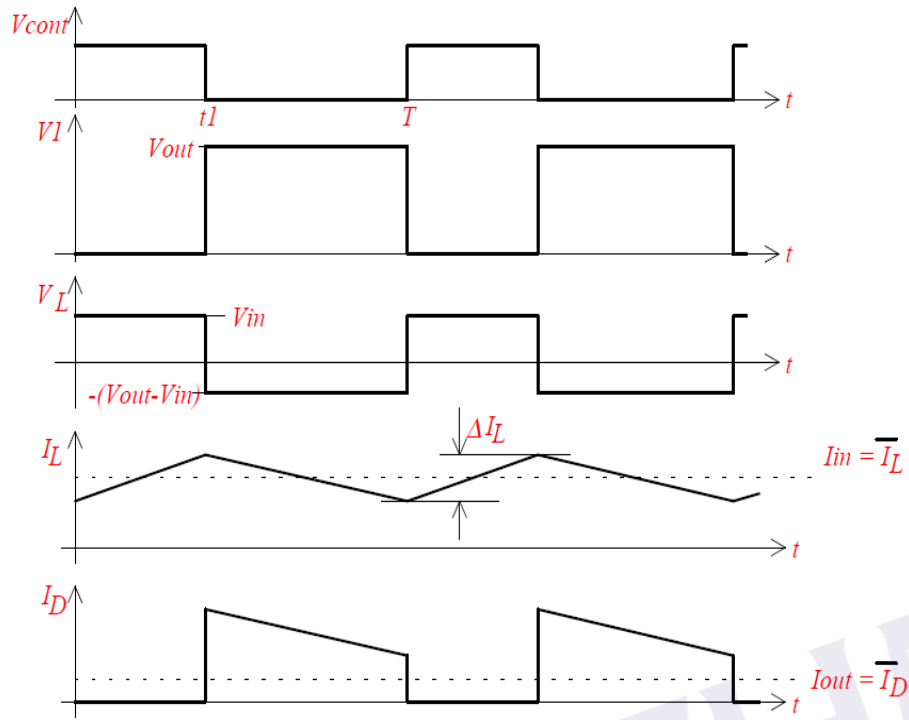


Figure 2.9: Voltages and currents of the boost converter

From the figure 2.9, the relationship of voltage and current for an inductor is:

$$i = \frac{1}{L} \int_0^t V dt + i_o, \text{ or} \quad (2.1)$$

$$V = L \frac{di}{dt} \quad (2.2)$$

For a constant rectangular pulse:

$$i = \frac{Vt}{L} + i_o \quad (2.3)$$

From this we can see that the current is a linear ramp, when the voltage is a constant pulse. When the transistor switches on the current is:

$$i_{pk} = \frac{(V_{in} - V_{Trans})T_{on}}{L} + i_o, \text{ or} \quad (2.4)$$

$$\Delta i = \frac{(V_{in} - V_{Trans})T_{on}}{L} \quad (2.5)$$

and when the transistor switches off the current is:

$$i_o = i_{pk} - \frac{(V_{out} - V_{in} + V_D)T_{off}}{L}, \text{ or} \quad (2.6)$$

$$\Delta i = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L} \quad (2.7)$$

Where V_D is the voltage drop across the diode, and V_{Trans} is the voltage drop across the transistor. Note that the continuous/discontinuous boundary occurs when i_o is zero. By equating through delta i , we can solve for V_{out} :

$$\frac{(V_{in} - V_{Trans})T_{on}}{L} = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L} \quad (2.8)$$

$$V_{in}T_{on} - V_{Trans}T_{on} = V_{out}T_{off} - V_{in}T_{off} + V_D T_{off}$$

$$V_{in}T_{on} + V_{in}T_{off} = V_{out}T_{off} + V_{Trans}T_{on} + V_D T_{off}$$

$$V_{in} - V_{Trans}D = (V_{out} + V_D)(1 - D)$$

$$V_{out} = \frac{V_{in} - V_{Trans}D}{(1 - D)} - V_D \quad (2.9)$$

We can also solve for the duty cycle as follows,

$$DV_{out} + DV_D - V_{Trans}D = V_{out} - V_{in} + V_D \quad (2.10)$$

$$D = \frac{V_{out} - V_{in} + V_D}{V_{out} + V_D - V_{Trans}} \quad (2.11)$$

If we neglect the voltage drops across the transistor and diode then:

$$V_{out} = \frac{V_{in}}{1-D} \quad (2.12)$$

In order to create a duty cycle, D , a PWM needed to be created.

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